



# EARTHQUAKES

Plate tectonics is a theory that models the earth's crust as a set of large "plates" that slowly bump and grind against each other. Most earthquakes are the result of strain release along zones of weakness (faults) in response to the slow movement of those crustal plates (Figure 1). The famous San Andreas fault is the boundary between the Pacific plate on the west and the North American plate on the east. On average, these two plates move past each other at two to three inches per year.

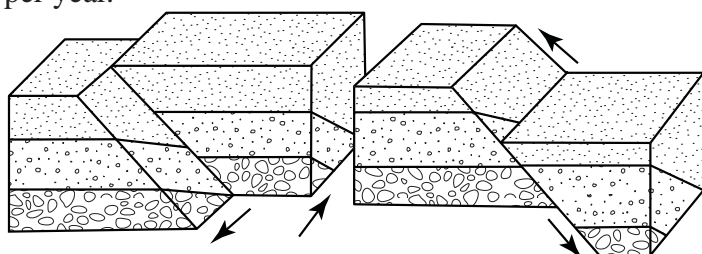


Figure 1. Movement of strike-slip (left) and dip-slip (right) faults (modified after Pakiser, 1991).

Virginia is located near the center of the North American plate and, thus, experiences a much lower rate of seismicity than California. Another difference is that California earthquakes often break the ground surface, while earthquakes in Virginia usually occur on faults at depths of from 3 to 15 miles. Thus, the earthquakes felt in the Commonwealth today generally have no relationship with faults seen at the surface.

Seismographs are instruments that record ground motion no matter what the source: for example - earthquakes, commercial mining blasts, and trains. The recordings of those ground motions are called seismograms.

## SEISMIC WAVES

When a fault ruptures, energy is released in the form of seismic waves. The first waves to reach the earth's surface are primary or "P" waves (Figure 2). P waves are compressional waves that travel at a speed of about four miles per second near the surface - faster as depth

increases. The next waves to reach the earth's surface are secondary or "S" waves. S waves are shear waves that move at a speed of about 1.5 miles per second. P and S waves are body waves that travel through the earth much like sonar waves travel through water. Surface waves, which are slower than S waves, travel along the surface of the earth much like waves at the surface of the ocean. S waves and surface waves cause the most destruction at the earth's surface.

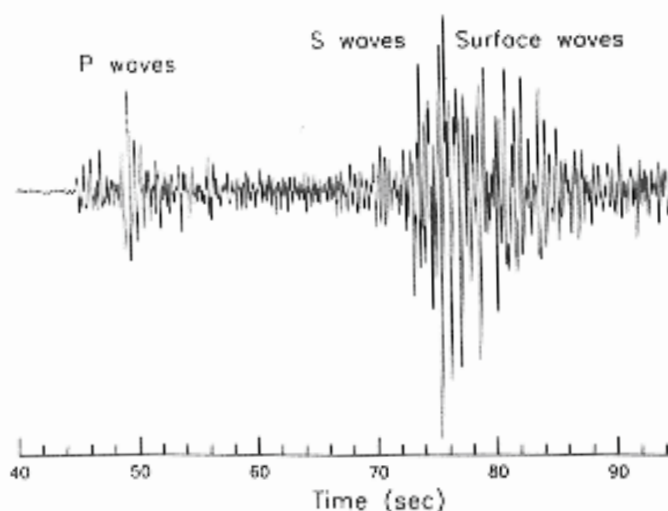


Figure 2. Seismogram of a March 15, 1991, central Virginia earthquake, magnitude 3.8, as recorded on a seismograph in Blacksburg, Virginia.

Figure 3 shows the travel paths of P, S, and surface waves. The time interval between the arrival of the P wave and S wave can be used to estimate the distance between the recording seismograph and the earthquake. One interesting aspect of shear waves is that they do not travel through fluids. It was this characteristic that led to the discovery that the earth's core was molten.

## EARTHQUAKE SIZE

Magnitude is the most common method of describing the "size" of an earthquake. The magnitude of an

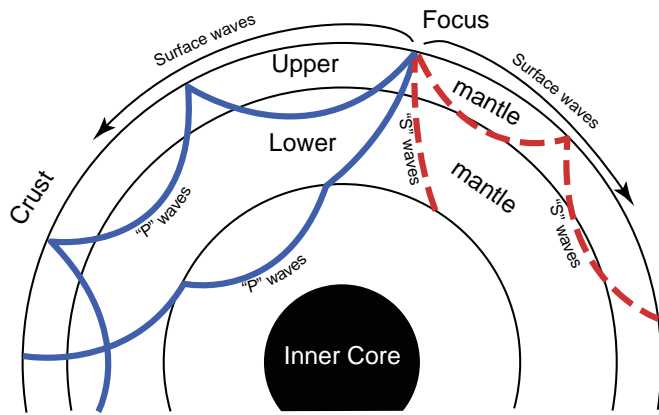


Figure 3. “Cut-away” view of the earth showing paths taken by seismic waves (modified after Pakiser, 1991).

earthquake is derived by measuring the amplitude of seismic waves on a seismogram. The amplitude readings from several seismograms and the distance from the earthquake to each seismograph are used to calculate a single magnitude value for each earthquake. The first and most well-known magnitude scale was developed by Charles Richter in the 1930s. Magnitude scales are logarithmic which means that an increase of one unit for example from four to five, implies a 10-fold increase in ground displacement. Moreover, a two unit increase in magnitude implies a 100 times (10 x 10) increase in ground displacement. The amount of energy released is about 30 times greater for each unit increase in magnitude. Thus, the energy released in a magnitude six earthquake is about 900 times (30 x 30) the energy released in a magnitude four earthquake. In general, a modern seismograph can record waves from a magnitude five earthquake anywhere in the world.

### EARTHQUAKE EFFECTS

The Modified Mercalli Intensity Scale is based on the effects experienced by individuals and the observed damage-- mainly to man-made objects (Figure 4). The scale uses Roman numerals from I to XII, where I would be for a site at which vibrations are slightly felt by very few observers, and XII implies total destruction. For earthquakes that occurred prior to the installation of seismographs, intensities are usually determined from newspaper accounts and diaries.

Whereas there is only one magnitude value associated with an earthquake, there can be many intensity reports for a single earthquake. In general, the intensity is greatest at the epicenter and decreases with distance from the epicenter. The observed effects of

	Modified Mercalli Scale	Richter Magnitude Scale
I	Detected only by sensitive instruments	1.5
II	Felt by few persons at best, especially on upper floors; delicately suspended objects may swing	2
III	Felt noticeably indoors, but not always recognized as an earthquake; standing autos rock slightly, vibrations like a passing truck	2.5
IV	Felt indoors by many; outdoors by few, at night some awaken; dishes, windows, doors disturbed; standing autos rock noticeably	3
V	Felt by most people; some breakage of dishes, windows, and plaster; disturbance of tall objects	3.5
VI	Felt by all, many frightened and run outdoors; falling plaster and chimneys, damage small	4
VII	Everybody runs outdoors; damage to buildings varies depending on quality of construction; noticed by drivers of autos	4.5
VIII	Panel walls thrown out of frames, walls, monuments, chimneys fall; sand and mud ejected; drivers of autos disturbed	5
IX	Buildings shifted off foundations, cracked, thrown out of plumb; ground cracked; underground pipes broken	5.5
X	Most masonry and frame structures destroyed; ground cracked, rails bent, landslides	6
XI	Few structures remain standing; bridges destroyed, fissures in ground, pipes broken, landslides, rail bent	6.5
XII	Damage total; waves seen on ground surface, lines of sight and level distorted, objects thrown up into air	7
		7.5
		8

Figure 4. Generalized relationship between epicentral Modified Mercalli intensities and magnitude (modified after Hansen, 1994).

an earthquake are very dependent on the earthquake magnitude, distance from the epicenter, and the type of geologic material underlying structures. Intensities are generally greater on soft soils (alluvium) than on solid rock. Seismic shaking can cause several effects on alluvium such as liquefaction. Liquefaction occurs when soil is shaken to the point where it can no longer support the weight of any object that happens to be on it. A recent example of widespread liquefaction was the sinking of houses and apartment buildings in

the Marina District of San Francisco during the 1989 Loma Prieta earthquake (the World Series earthquake). Other strong earthquake shaking ground effects are landslides, fissuring, and slumping.

REGIONAL EARTHQUAKES

Virginia, like most states on the eastern seaboard, has a moderate level of risk from earthquakes. The largest earthquake known to have occurred in the region was the 1886 Charleston, South Carolina, earthquake (estimated magnitude 6.6-6.9). That quake was felt as far north as Canada, as far west as Missouri, and as far south as Cuba. Table 1 lists the damaging effects of the 1886 earthquake at some sites in Virginia. Recent studies indicate that large earthquakes have occurred near Charleston in the centuries prior to the 1886 shock. Although earthquakes outside Virginia (e.g. 1886 Charleston, South Carolina) have caused damage in the Commonwealth in the past, the most likely sources for future damaging shaking in Virginia are the local active areas within the state like Central Virginia and Giles County.

Locality	Effects
Culpeper	Chimneys thrown down
South Boston	Chimneys thrown down
Henrico County	Difficult to remain standing
Richmond	Population in the streets; chimneys knocked down; prisoners riot in cells at penitentiary; militia and police called out to restore order; pictures and plaster fell from the walls; many residents felt nausea caused by the vibrations; people thrown from their feet
Abingdon	Plaster shaken down
Chesterfield County	Chimney and plaster damage
Danville	Chimney damage; walls cracked
Farmville	Plaster and chimney damage
Lee County	Plaster and chimney damage; broken windowpanes
Lynchburg	Chimney damage
Norfolk	Chimneys broken; light framework thrown down; large warehouse damaged; panic at Opera House; many people nauseated
Petersburg	Windowpanes broken
Patrick County	Bricks thrown from courthouse
Surry County	Plaster damage
Williamsburg	Plaster damage

Table 1. Effects of the Charleston Earthquake of 1886 in Virginia.

VIRGINIA EARTHQUAKES

Since 1774, the year of the earliest documented Vir-

ginia earthquake, there have been over 300 earthquakes in or near the Commonwealth. Of those, 18 earthquakes had reports of intensity VI or higher (Table 2). The largest earthquake in Virginia was the 1897 Giles County shock. The maximum intensity was VIII in Giles County, and it was felt over 11 states (approximately 280,000 square miles). The estimated magnitude for this event was 5.8, making it the third largest earthquake in the eastern United States in the last 200 years (second largest in the southeastern U.S.).

Date (Yr-Mo-Day)	Maximum Intensity	Felt Area (Sq Miles)	Locality
1774-02-21	VI	58,000	Petersburg
1833-08-27	VI	52,000	Goochland Co.
1852-04-29	VI	174,500	Grayson Co.
1852-11-02	VI	32,000	Buckingham Co.
1875-12-23	VII	50,000	Buckingham Co.
1885-10-10	VI	25,000	Nelson Co.
1897-05-03	VII	89,500	Giles Co.
1897-05-31	VIII	280,000	Giles Co.
1998-02-05	VI	34,000	Wytheville
1907-02-11	VI	5,600	Arvonnia
1918-04-10	VI	65,000	Luray
1919-09-06	VI	-	Warren Co.
1929-12-26	VI	1,000	Albemarle Co.
1954-01-02	VI	-	Bell Co., KY / Lee Co., VA
1959-04-23	VI	2,050	Giles Co.
1969-11-20	VI	100,000	Elgood, WV/ Rich Creek, VA
1975-11-11	VI	-	Giles Co.
1976-09-13	VI	9,000	Carroll Co.

Table 2. Earthquakes in and around Virginia (VI or greater).

In 1963, as part of the Worldwide Standard Seismograph Network program, seismographs were installed at Georgetown University in Washington, DC, and at Blacksburg, Virginia. In 1977, several more seismographs were installed and operated by Virginia Tech and the Virginia Department of Mines, Minerals, and Energy - Division of Mineral Resources. From 1978 through 1993, over 160 earthquakes were detected in and around the Commonwealth. Twenty-six of those earthquakes were felt by local residents. This averages out to about ten earthquakes per year of which one or two are felt. (This apparent increase in the number of events-300 in 200+ years versus 160 in the last 16 years is a result of the recent 130+ small earthquakes not felt locally but detected by seismographs.) The largest earthquake detected since 1978 was the 1984 Cunningham, Virginia earthquake with a magnitude

of 4.0, a maximum intensity of V, and was felt over 12,000 square miles. Other activity worth noting includes the 1981 Scottsville, Virginia earthquake sequence in which three felt earthquakes (maximum intensity IV) with magnitudes of 3.4, 3.2, and 2.9, occurred within an eight minute period. A series of 11 small (magnitude 1.5-2.2) shallow earthquakes were strongly felt (maximum intensity V) in Richmond in the winter of 1986-1987. One of the most persistent areas of activity is in Carroll County, Virginia. Since 1978, five small felt earthquakes have occurred near Hillsville, Virginia.

## REFERENCES

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- Paliser, L. C., 1991, Earthquakes: U. S. Geological Survey pamphlet, 20 p.
- Prepared by M. S. Sibol, M. C. Chapman, and S. S. Johnson; revised 5/2007.

### ***Division of Mineral Resources***

*900 Natural Resources Drive, Suite 500  
Charlottesville, VA 22903*

***Sales Office:*** (434) 951-6341 ***FAX :*** (434) 951-6365

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